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EMOTIONAL SPEECH PERCEPTION IN PRELINGUALLY AND POSTLINGUALLY DEAF COCHLEAR IMPLANT USERS: A REVIEW

MAURA L. KRESTAR
Department of Clinical Health Sciences
Texas A&M University-Kingsville
700 University Blvd, MSC 177A
Kingsville, TX 78363 USA
E-mail: Maura.Krestar@TAMUK.edu

GABRIELLA SANCHEZ
Department of Clinical Health Sciences,
Texas A&M University-Kingsville
700 University Blvd, MSC 177A
Kingsville, TX 78363 USA

ABSTRACT

Accurate and meaningful verbal communication between individuals requires the use of both emotional semantics and emotional prosody. When hearing is impaired, the auditory signal becomes degraded, making the perception of emotional prosody difficult. Such is the case with cochlear implants (CIs). Limitations of CI technology may cause diminished or lost cues of emotional speech. A degraded auditory signal, like the one experienced by individuals using CIs, affects the way individuals perceive multiple aspects of the speech signal, including emotional speech. The purpose of this brief review is to explain some of the difference between how prelingually deaf CI users and postlingually deaf CI users perceive emotional speech. Evidence shows that prelingually deaf CI users are able to produce suprasegmental aspects of speech, but have difficulties correctly identifying the emotional correlates of speech. Postlingually deaf CI users also have trouble identifying prosodic cues in speech when visual cues are removed. More research is needed to determine exactly how much of the subtle cues available in emotional speech is lost due to the technical limitations of the CI. More research is also needed to determine how accurately the CI user from both prelingual and postlingual groups interpret the messages they hear based on respective auditory cues and visual cues.

Keywords: emotional speech, emotional prosody, speech perception, cochlear implant, prelingual deafness, postlingual deafness

INTRODUCTION

Accurate and meaningful verbal communication between individuals requires the use of both emotional semantics and emotional prosody. The acoustic signal of a simple phrase like, “It is raining outside” can carry vastly different meanings depending on emotional prosody. One can imagine how the emotional prosodies may vary based on whether the speaker had plans to go to the beach that day or the speaker just experienced 160 days of drought. To fully perceive a verbal message, the listener must perceive not only the linguistic content of a speech signal that makes up the words, but also the paralinguistic components that provide meaning beyond the words alone, especially emotional prosody.

When hearing is impaired, the auditory signal becomes degraded, making the perception of emotional prosody difficult. Some individuals who experience hearing impairment can improve their hearing using cochlear implants (CIs), explained in more detail later. In 2012, worldwide, about 324,000 people used CIs to treat hearing loss; approximately 58,000 adults and 38,000 children from that group were from the United States (National Institute on Deafness and Other Communication Disorders, 2016). Despite the positive outcomes of CI technology, CI users still receive a degraded, less than ideal, auditory signal. In addition, auditory sensation and perception processes differ in CI users depending on the timing of implantation (i.e., pre- or postlingual implantation).

The timing of implantation seems to be especially influential in the ability to sense and perceive emotional speech. For these reasons, the current paper briefly reviews the differences between emotional speech identification and perception in individuals who have received CIs pre- or postlingually, focusing on the perceptual level, and identifying areas of study lacking research that would benefit individuals with hearing impairment, those with CIs, and members of their treatment teams.

HOW PEOPLE WITH NORMAL HEARING (NH) PERCEIVE EMOTIONAL SPEECH

To understand the workings of a CI and the differences between what an individual with and without a CI hears, it is first necessary to understand how people with normal hearing (NH) perceive emotional speech. The perception of emotional speech begins with auditory perception of aspects of the acoustic signal comprised by a speaker’s voice. NH occurs when sound waves are channeled through the external auditory canal and strike against the tympanic membrane. The vibration of the tympanic membrane converts the auditory pressure waves to mechanical energy, which sets the ossicles in the middle ear into motion. From there, the mechanical energy is transformed into hydraulic energy via the cochlear fluid in the middle ear. The hydraulic waves stimulate the cochlear hair cells, which send the impulses through the fibers of the vestibulocochlear nerve to the cochlear nuclear complex located within the brainstem. From there the nerve impulses are transmitted to multiple points in the brainstem and thalamus before projecting to the primary auditory cortex (Machery & Carlyon, 2014).

The auditory perception of emotional speech includes several components of the voice signal, including fundamental frequency, duration, and intensity, but also energy distribution (the ratio between energy in high frequency and low frequency), formant location, and rate of speech (tempo and duration; Bachorowski, 1999; Most & Aviner, 2009). For example, anger typically includes an increase of the mean, greater variability, and wider range of the fundamental frequency and an increase in the average energy of the acoustic signal of speech, while sadness typically includes a decrease in mean fundamental frequency, range, and energy (Banse & Scherer, 1996).

In terms of emotional intonation identification, accuracy rates individuals with NH vary greatly, but tend to perform better than chance (Banse & Scherer, 1996; Most, Wiesel, & Zaichik, 1993; Pereira, 2000). Research suggests that NH listeners typically classify emotional speech along two underlying dimensions: valence and arousal such that various emotional intonations can be plotted along an axis representing each dimension (Sauter, Eisner, Calder, & Scott, 2010).

In a discussion of emotional speech perception, it is necessary to acknowledge that a large number of emotional social interactions outside of the laboratory involves visual information in addition to auditory. Not surprisingly, NH listeners identify emotional intonations better when both auditory and visual information (i.e., facial expressions) comprise the sensory stimuli compared to auditory information alone (Most et al., 1993, Rigo & Lieberman, 1989; Scherer & Ellgring, 2007; Wallbott & Scherer, 1986). The facial expressions of the speaker appear to add a visual cueing system to the process of perceiving emotions within speech. Nevertheless, many situations require listeners to perceive emotional prosody when no visual information is available. Thus, it is necessary to understand the way various hearing populations perceive emotional speech.

HOW PEOPLE WITH COCHLEAR IMPLANTS (CIS) PERCEIVE SOUND

To qualify for a cochlear implant, the prospective candidate must have profound, bilateral, sensorineural hearing loss (Gifford, 2011). Sensorineural hearing loss is characterized by the dysfunctional neural transduction of sound. The problem can occur with the inner ear, auditory nerve, or auditory centers in the brainstem or temporal lobe. The loss of hearing may also be caused by disease or disorders that damage the cochlea or auditory nerve (Machery & Carlyon, 2014). A cochlear implant serves as a neural stimulator that bypasses the functions of the damaged sensory receptors of the inner ear. Electrical currents from the device, which mimic those of sound signals, directly stimulate the ganglion cells of the auditory nerve. From there, the signals are transmitted to the auditory cortex, which interprets the signals as sound (Hodges & Balkany, 2002; Machery & Carlyon, 2014).

An individual who has a CI does not transmit sound from outside of the ear to the brain in the same way as an individual with NH. The internal portion of a CI consists of 12 to 22 electrodes surgically placed within the cochlea in a tonotopic representation that mirrors a biological cochlea. The electrodes are placed near different auditory nerve fibers that are consistent for coding different frequencies of sound. The external portion of the CI uses microphones to collect sound stimuli from the environment and convert them to electrical signals via the encoded speech processor.

The signal is then passed from the external transmitter to the internal receiver, which communicate to one another through coils held in place by localized magnets across the skin of the skull. The receiver decodes the signal and sends an impulse to the targeted nerve fibers, which produce action potentials that are consistent with the original sound. The brain then perceives the action potentials as words and sounds with meaning (Clark, 2004; Machery & Carlyon, 2014).

Unfortunately, limitations posed by CIs can produce a subpar auditory signal that may cause difficulty in perceiving sound. Specifically, CI users tend to have difficulty in distinguishing the frequency, amplitude, and temporal domains of hearing (Başkent, Gaudrain, Tamat, & Wagner, 2016; Machery & Carlyon, 2014, Meister, Landwehr, Pyschny, Wagner, & Walger, 2011), the exact domains of speech that make up emotional prosody. Thus, individuals with CI tend to exhibit difficulty recognizing and identifying emotional intonations in speech.

Auditory emotion recognition studies with semantically neutral stimuli repeatedly find lower scores in those with CIs compared to those with NH (Agrawal et al., 2013, Kalathottukaren, Purdy, & Ballard, 2015; Luo, Fu, & Galvin, 2007; Pereira, 2000). In particular, fine structure information contained in pitch and harmonics, vital to emotional prosody, present limitations for today's CI systems (Galvin, Fu, & Nogaki, 2007; Kang, Colesa, Swiderski, Su, Raphael, & Pfingst, 2010; Kong, Cruz, Jones, & Zeng, 2004; Kong, Mullangi, Marozeau, & Epstein, 2011). Nevertheless, individuals with CIs can distinguish less fine acoustic differences, such as those that differentiate sentence from question prosody (Rosen, 1992). Recent research has tested emotion identification performance by breaking down the emotional speech signal into its contributing components of pitch (e.g., Pereira, 2000), duration/tempo (e.g., Schroder, Cowie, Douglas-Cowie, Westerdijk, & Gielen, 2001), and intensity (e.g., Pereira, 2000; Schroder et al., 2001).

PRELINGUALLY DEAFENED INDIVIDUALS WITH CI

The term "prelingually deaf" refers to people either born without the ability to hear or who lost their hearing before the development of their language skills. To date, few studies have investigated the perception of emotional speech for prelingually deafened individuals with CI. However, some studies examine how this population perceives speech in general.

GENERAL SPEECH PERCEPTION BY PRELINGUALLY DEAFENED INDIVIDUALS WITH CI

A study done by Most and Aviner (2009) compared the emotional perception abilities of people with NH, hearing aids, and CIs (prelingual). Their findings indicated that individuals with NH performed better when identifying emotional speech than both hearing impaired groups when it came to auditory, visual and auditory-visual modalities of communication. The individuals with hearing aids and CIs performed similarly across modalities. Most and Aviner (2009) suggested that the CI exposes the individual to more of the verbal and social aspects of emotional perception than they would experience without it relative to the hearing aid. Additionally, individuals who were implanted earlier had slightly better auditory perception than those implanted later in life.

The ability of CIs to enhance speech perception in general is further supported through a study done by Holly Fryauf-Bertschy and colleagues (1997). In the study, speech perception tasks were administered to prelingually deaf children with CI at annual levels following the implementation of the external hardware of the CI. The results showed that, regardless of the age of implantation, children exhibited notable improvement in the perception of speech. The authors suggest that the children have the improved their understanding of speech over time based on the results of the annual tests. The authors also explained that the ability of the children to perceive the phonemic structure of the words paired with the skills of lipreading may have benefited their communicative ability overall (Fryauf-Bertschy, Tyler, Kelsay, Gantz, & Woodworth, 1997). This study shows that although the ability to perceive speech may be present, the listener still may not be able to fully understand the semantic properties of what they hear through the auditory modality alone.

A similar 2008 study examined a group of 21 patients with CI under the age of 12 years old. The participants each used the CI for at least one year, with only 2 of the participants deemed to be postlingual CI users. The researchers looked for signs of detection, discrimination, identification, recognition, and comprehension of the audio stimuli presented to the participants in a series of seven tests. The results of the study indicated improvement in the perception task performance on all counts compared to pre-operative measures. The authors discussed the possibility that prelingually deafened children with CI will continue to develop their speech recognition skills over time (Mukhtar, Khan, Ahsan & Shah, 2008).

Again, the researchers only measured the development of skills up to one year after implantation. No data measured if and when the skills of the participants reached a plateau. Thus, it is difficult to make a comparison between the auditory perception skills of the prelingually deafened CI population and their hearing peers. The prelingually deaf CI population tends to be more accurate with speech perception when acoustic cues are paired with visual cues. This possibly results from the CI serving as an aid perceiving visual cues when implanted prelingually by complementing the visual input received from a speaker. Support for such claims come from, for example, Fryauf-Bertschy and colleagues (1997), discussed above, who found that overall communication abilities in prelingually deaf individuals with CI can be further enhanced when lipreading is available to the listener. More recent findings (e.g., Bergeson, Pisoni & Davis, 2005) parallel the views of Fryauf-Bertschy and colleagues' (1997) in regard to the benefits of auditory stimuli paired with lipreading. Bergeson and colleagues (2005) found that the CI could serve as an aid perceiving visual cues when implanted prelingually by complementing the visual input received from a speaker and providing a more complete communicatory signal.

A retrospective review from 2004 sheds light on the lack of information regarding the development of perception skills. The review examined the possibility of CI advances providing better speech understanding to prelingually deaf adults (Teoh, Pisoni, & Miyamato, 2004). This particular review differentiates itself from the others due to its focus on the adult population instead of children. The study states that prelingually deafened adults with CI usually reach a plateau in audiologic performance approximately one year after implantation. The review indicated that the older the patient at the time of implantation, the slower the rate of improvement. In addition, the performance of prelingual CI groups was consistently below the performance of the postlingual adult patients with CI. The authors suggested that patient characteristics were most likely the major contributing factors responsible for the outcomes of the study, not the properties of the CI device. Some of these characteristics include etiology of disease, modes of communication, and levels of education (Teoh et al., 2004). The results from this review show that the older population of prelingual CI users tends to find it more difficult to adapt to the new CI technology. Perhaps this is due to the brain's lack of plasticity compared to younger generations (Park & Bischof, 2011) or, as mentioned by the authors, specific characteristics of the individual.

Regardless of the causes related to the differences in performance of prelingual and postlingual CI users, in order to fully understand the way that CIs affect emotional speech perception in this population, it is important to understand how the hearing mechanism of this population adapts to the CI technology. The studies discussed focus on how this population's performance improves after the implementation of CI but information regarding the specific skills attained post-CI is limited. The limitations involved in speech perception in prelingual CI users will be further discussed in terms of emotional speech perception in the following subsection.

EMOTIONAL SPEECH PERCEPTION IN PRELINGUALLY DEAF INDIVIDUALS WITH CI

Several studies have documented delays in ability to identify emotion in speech by prelingually deaf individuals with CI relative to their NH peers (e.g., Geers, Davidson, Uchanski, & Nicholas, 2013; Luo, Fu, & Galvin, 2007). The following outlines some others that provide insight into the way prelingually deaf individuals with CI perceive emotional speech.

In 2011, Liwo tested prelingually deafened children with CI and children with hearing aids all under the age of two on the production of the prosodic elements of speech. Research within this subfield follows the theory that more successful prosody production correlates with more successful prosody perception. Findings showed that the group with CI performed much better than their hearing aid peers in terms of producing suprasegmental features of speech. The group difference suggests that the children with CI increased their suprasegmental feature production through the process of listening to the language of those around them (Liwo, 2011), while the children with hearing aids did not have that opportunity. The improvement in performance may suggest that their ability to perceive the suprasegmental aspects of speech, one of which is prosodic intonation, a hallmark of emotional speech production, is enhanced through cochlear implantation.

A 2008 study examined prelingually deaf children aged 7-13 years with unilateral CI on their ability to correctly identify facial affect and emotional speech prosody (Hopyan-Misakyan, Gordon, Dennis, & Papsin, 2008) using the Diagnostic Analysis of Nonverbal Accuracy-2 (Nowicki & Duke, 1994). On a series of pre-test measures, the CI group listened to and repeated monosyllabic words with 70-80% accuracy, indicating that they were indeed able to perceive the speech cues within the words at average to loud conversation levels..

The results indicate that although the CI provides the ability to perceive acoustic cues in speech, it perhaps does not allow for the accurate conveyance of prosodic elements of speech to the listener. This, as mentioned previously, may be due to the listener reaching a plateau in their skill level with the CI. Another reason may be that the CI technology is limited in what the channels can convey through auditory nerve stimulation. The CI technology alone does not convey auditory signals in the same manner as the NH mechanism. CI is only able to stimulate a part of the cochlear nerve and has restrictions in spectral and temporal cues of auditory input(Hodges & Balkany, 2002; Moore & Shannon, 2009).

The biggest concern for the purposes of this review is how much of the subtle cueing in emotional speech is lost due to the limits of the CI mechanism. Although the prelingual CI population may be able to perceive emotional prosody of speech, as demonstrated in Liwo’s study, it is unclear how this population relates the input from the CI to emotional correlates within speech (2011).

POSTLINGUALLY DEAFENED INDIVIDUALS WITH CI

The postlingually deafened population is comprised of individuals who had access to NH throughout their language learning experience, and then lost such access (Cowie & Douglas-Cowie, 2011). The causes of the onset of deafness could be due to traumatic brain injuries, disease, exposure to extremely loud noise, ototoxic medicine or simply age (ASHA, n.d.). The way that their brains adapt to the reintroduction of an auditory stimulus after its prolonged absence makes postlingually deafened individuals with CIs unique.

GENERAL SPEECH PERCEPTION BY POSTLINGUALLY DEAFENED INDIVIDUALS WITH CI

Evidence supports the brain’s adaptation to varying stimuli due to the reorganizational properties of plasticity (Kułak & Sobaniec, 2004; Wilson & Dorman, 2008). After cochlear implantation, the decrease in auditory stimuli to the auditory nerve causes structural and functional differences within the central auditory system (Moore & Shannon, 2009), which will be discussed in this section.

Several studies results showed that while using the CI, the auditory cortex was increasingly more active over 3 years post-implant. However, there was also an increase in visual cortical activity in the same participants; the visual cortices showed an increase in activity in response to speech and other meaningful sounds, but not to noise alone. The authors suggest that postlingually deaf individuals with CI show an increase in activity within the visual cortex while listening to speech. This increase may be related to an enhancement of lipreading activity (Giraud, Price, Graham, Truy & Frackowiak, 2001; Zatorre, 2001).

The findings of Giraud and colleagues (2001) are important for the purposes of this review because they provide information on the reorganization of the brain after CI. Postlingual adults with CI undergo a change in brain functioning that requires them to depend, not on hearing cues alone, but on the visual stimuli provided by the speaker, with a stronger reliance on lipreading. With these two modalities working together, the question of how accurately the listener interprets the meaning of what is being said, as well as the emotions being conveyed by the speaker, must be examined.

Another study conducted by Anderson and colleagues in 2017 presented evidence regarding how the plasticity of the brain works with CI. The authors examined post-CI changes to the superior temporal cortex (STC), which aids in receiving auditory signals from both ears. According to the authors, the brain changes suggested that the longer the time frame between the onset of deafness and the CI procedure, the greater the possibility that auditory performance with a CI may be negatively impacted. The results suggest that this effect resulted from limitations in STC performance (as a result of deafness) and the increased responsiveness of other brain areas responsible for sensory modalities such as sight and touch. In other words, the STC is more active before the onset of deafness. With the absence of the auditory stimuli traveling to the STC, the brain begins to focus on other senses to compensate for the loss of the auditor stimuli. Evidence from Anderson’s study also shows that postlingually deaf individuals tend to show a higher reliance on visual stimuli in audio-visual situations for auditory comprehension purposes. This is a compensatory behavior caused by the individual’s need to compare the new auditory signals to the old auditory input that is stored in their memory from before the onset of deafness. The individuals form connections between the new auditory input and their respective visual speech cues. The important elements of Anderson, Lazard, and Hartley’s study lie in the way the evidence illuminates the way the brain adapts to the absence of a once regular stimuli and then the reintroduction of the stimuli in a modified state.

EMOTIONAL SPEECH PERCEPTION IN POSTLINGUALLY DEAF INDIVIDUALS WITH CI

A study done by House (1994) compared the emotional perception of postlingually deafened CI users to that of NH peers. As previously discussed, intensity and fundamental frequency were both used as primary cues for emotional perception, and sometimes can be very similar across emotional intonations. Thus, due to the similarities between the intensity and fundamental frequencies between happiness and anger as well as sadness and neutrality, it would be understandably difficult for the CI technology to tell them apart (Banse & Scherer, 1996; House, 1994). As stated previously, the CI technology is not as advanced as the normal human ear, and thus, may not be as readily equipped to perceive the subtle cues of emotional speech.

Another study by Morris, Magnusson, Faulkner, Jönsson, and Juul (2013) examined he identification of vowel length, word stress, and compound words in the postlingual population. The participants all received CI in adulthood and were compared to a control of NH peers. The results of the study showed that the CI group could not identify the prosodic cues in the sample as well as the control group. The authors of the study determined that the discrimination of the intensity of sounds were predictive of the participants’ performance on the prosodic tasks. The older participants performed more poorly, indicating that age may also predict the accuracy of stimuli identification.

Similarly, Gilbers and colleagues (2015) presented auditory stimuli to comparable participants without visual cues. The audio consisted of nuanced phrases devoid of any semantic meaning. Thus, the participants were not able to infer any contextual clues that may have assisted them in accurately reporting the emotion being expressed by the speaker. Again, this study found that participants with NH did better than CI participants in emotion recognition. The two groups showed different behaviors when presented with the stimuli, indicating that different strategies were being utilized for perception (Gilbers et al., 2015). More specifically, results suggested that NH listeners used mean pitch as a more salient cue and CI users found pitch range cues to identify emotion. Due to limitations in the sound transmission of the CI, certain speech cues, such as the fundamental frequency, may be more difficult to discern for a CI user (Gilbers et al., 2015). The CI user must adjust their perceptual strategies to accommodate the new CI input.

This type of readjustment is a distinguishing factor between prelingually deaf individuals and the postlingually deaf population. People who are congenitally (prelingually) deaf do not undergo reorganization of input processing to the extent that postlingually deaf individuals do. The auditory and language processing centers of the brain in a prelingually deaf individual will be used to deciphering more tactile and visual information in the absence of auditory stimuli (Merabet & Pascual-Leone, 2010). Postlingually deaf individuals have the slight advantage of comparing the auditory cues in the stimulus through their CI to their perception before the onset of deafness as previously suggested.

Clearly, speech perception for postlingually deafened individuals with CIs is affected by the plasticity of the brain. The auditory and visual cortices increase their activity as time progresses after implantation when exposed to speech sounds (Giraud et al., 2001; Zattore, 2001). The increase in the visual cortex in response to speech after CI may be due to the development of a higher dependence on visual cues to decipher speech. After implantation, the postlingual CI population most likely compensates for missed auditory signals via lipreading cues. It is also possible that the comparison of old auditory signals to the new auditory input requires visual components to bridge the gaps (Anderson, et al., 2017). It is important to note that the longer the gap between the onset of deafness and the implementation of CI, the greater the chances that the auditory performance will be negatively impacted.

DISCUSSION AND CONCLUSION

This review explained emotional speech perception in specific individuals: prelingually and postlingually deafened CI users. As discussed by Machery et al. (2014), individuals with CI perceive auditory stimuli differently than the normally hearing population. Technological limitations of the CI paired with the sensory limitations of the deaf ear itself may make speech sounds more difficult to clearly perceive (Machery et al., 2014). Because postlingually deafened CI users have experience with hearing the nuances of emotional speech, they tend to exhibit differences in auditory perception tasks using emotional speech stimuli. By contrast, the speech perception of postlingually deafened individuals with CI is affected by the plasticity of the brain. Clearly, humans communicate emotionally in more than one sensory modality, making it difficult to study the perception of emotional speech without acknowledgement of the visual facial expressions that often accompany the emotional speech. Further research should address the contribution of multiple sensory modalities, including how individuals with CIs may compensate for a degraded auditory signal by relying more on the accompanying visual signal when it is available.

Future research should address just how much of the subtle cues available in emotional speech are lost due to the technical limitations of the CI. More research is also needed to determine how accurately the CI user from both prelingual, and postlingual groups interpret the messages they hear based on auditory cues and visual cues. Both of these additions to research would help improve the rehabilitative process for both populations after implantation. There should also be research to determine how well this population produces emotional aspects of speech. With information regarding how these groups perceive emotional speech in spontaneous communication, the rehabilitation process can be tailored further to more functional communication needs for this population.

Optimal verbal human communication involves a complex combination of linguistic content presented within a paralinguistic context. The paralinguistic speech component of emotional prosody plays such a large role in human communication that it can completely change the meaning of an utterance. For these reasons, researchers in the field of speech perception should fully understand all situations that present difficulty identifying and understanding emotional prosody, especially CIs. With an understanding of the ways individuals with CIs, prelingual and postlingual, perceive emotional speech combined with an understanding of the causes of difficulties that CIs present, the verbal expression of and auditory resception of emotional prosodyr may be further improved for individuals with CIs.

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